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PIEZOELECTRIC ACTUATOR

[0001] Prior Art

[0002] The invention relates to a piezoelectric actuator, for example for actuating a mechanical component such as a valve or the like, according to the features in the preamble to the main claim.

[0003] It is generally known that the so-called piezoelectric effect can be used to produce a piezoelectric element partly comprised of ceramic material with a suitable crystalline structure. When an external electrical voltage is applied, a mechanical reaction of the piezoelectric element occurs, which produces a pressure or tension in a direction that can be predetermined as a function of the crystalline structure and the regions to which the electrical voltage is applied. Such piezoelectric actuators are particularly suitable for use in rapid and precise switching procedures, for example in various injector-equipped gasoline or diesel injection systems for internal combustion engines.

[0004] These piezoelectric actuators can be structured in a number of layers, in the form of so-called multilayered piezoelectric actuators in which the layers are respectively interleaved with the electrodes that are used to apply the electrical voltage. To that end, piezoelectric sheets with printed electrode surfaces serving as inner electrodes are stacked in alternation. In this design, a sheet has its connection only on a connection side and on the opposite side, must have an edge without an inner electrode and this edge must be provided with an insulating space. The two sides are then connected on the outside by means of outer

electrodes. The piezoelectric actuator is thus produced in a known way with a number of plates, much like a capacitor.

[0005] These known multilayered piezoelectric actuators predominantly have rectangular inner electrodes with corners that are usually sharply chamfered on opposite sides, on which the connecting potentials are routed to the surface. In this case, the two inner electrode potentials can then be disposed next to each other on the surface, with a ceramic layer between them. These piezoelectric actuators, however, are operated with field intensities that require an insulation of the open leakage paths in the ceramic between the potentials. Suitable lacquers or insulating materials with favorable adhesion and favorable breakdown and insulation characteristics can, for example, be applied in the usual way, by spraying or immersion.

[0006] The above-described piezoelectric actuators with inner electrodes routed outward on alternating sides often tend to fail in regions in which the inner electrodes have relatively sharp angles. Since as a rule, the edges on the piezoelectric actuator have to be broken at the mechanically soft piezoelectric ceramic, this yields the above-described corners that are chamfered at an angle of 45°. If inner electrodes protrude outward at these points, then an increased danger of short-circuiting is present there for the reasons mentioned above. Since the electrical field intensity is in inverse quadratic proportion to the curvature radius of the equipotential surface, extremely high field intensities are generated there, which then cause the piezoelectric actuators to fail in this region due to short-circuiting.

[0007] It should also be noted that due to physical effects, an insufficient insulation thickness is built up at the sharp edges, i.e. due to a retraction of the insulation lacquer possibly applied. As a result, at the points in which the most insulation is in fact required by the increased field intensity due to the corner effect, the least insulation thickness is actually produced. It would be possible to apply a relatively large amount of lacquer in order to obtain a greater insulation lacquer thickness at the edges, but this can lead to lacquer fractures in the areas in which the lacquer is excessively thick.

[0008] DE 199 28 191 A1 has disclosed a multilayered piezoelectric actuator in which the piezoelectric layer that does not have an inner electrode to be contacted is recessed toward the inside in a predetermined region.

[0009] Advantages of the Invention

[0010] The piezoelectric actuator described at the beginning, which can be used, for example, to actuate a mechanical component, is comprised of a multilayered structure of piezoelectric layers with inner electrodes disposed between them. According to the invention, in the region of the corners or edges, on the sides of the piezoelectric actuator – which is chamfered here – where the inner electrodes are routed with alternating polarity to the respective outer electrodes, the inner electrodes have a contour that makes it possible to achieve a lower field intensity between the inner electrodes of opposite polarities in the structure of piezoelectric layers.

[0011] According to a first advantageous embodiment form, the chamfers at the corners of the piezoelectric actuator are embodied so that the edge on the side that is not contacted by the outer electrodes has an obtuse angle. Providing an obtuse or wide angle on the side of the edge segment at which the reciprocal electrodes extend outward makes it possible to easily avoid field peaks in the piezoelectric actuator in regions of inner electrodes that protrude outward beyond the piezoelectric layers, but on opposite sides. This drastically reduces the risk of a short circuit and consequently increases the reliability of the piezoelectric actuators.

[0012] The obtuse angle can be produced on the one hand by the electrode surface being adapted to the outer contour of the piezoelectric actuator. This occurs through the shaping in the so-called "green state" of the piezoelectric actuator before the sintering or through a hard machining after the sintering. Another possibility is to produce an obtuse angle already as part of the printed image in the production of the inner electrode.

[0013] According to a second advantageous embodiment, the chamfers at the corners of the piezoelectric actuator are embodied so that the edge is rounded, at least on the side that is not contacted by the outer electrode. In this case, it is also advantageously possible for the chamfers at the corners of the piezoelectric actuator to be embodied so that the entire corner of the piezoelectric actuator and correspondingly, the contour of the respectively non-contacted inner electrode to be rounded. On the other hand, it is also possible for the chamfers at the corners of the piezoelectric actuator to be simply embodied so that the entire corner of the piezoelectric actuator is simply beveled and the contour of the respectively non-contacted inner electrode is rounded.

[0014] It is also advantageous, according to one modification of the invention if, on the side that the inner electrode of the respective other polarity is contacted, the contour of the respectively non-contacted inner electrode is embodied so that it is recessed by a preset amount from the outer contour of the piezoelectric actuator. The contour of the respectively non-contacted inner electrode in this case can be recessed to correspond to the outer contour of the piezoelectric actuator.

[0015] In particular this embodiment can easily assure that sufficient insulation material remains between the non-contacted inner electrode and the surface of the piezoelectric actuator and consequently between the two electrode potentials. The powerful field intensities do not cause premature breakthrough damage; the additional covering and insulating ceramic layer here serves as a replacement for a possibly insufficient thickness of lacquer layers on the surface.

[0016] According to the invention, damage and slight abrasion tracks at the edges no longer inevitably lead to arc-overs and the lacquer thickness on the surface can be reduced on the whole and therefore no longer risks fracturing and more easily follows along with expansions of the actuator, without fracturing over time. In addition, the lacquer adheres altogether better in the corners and edges embodied according to the invention than it does at relatively sharp edges.

[0017] Drawings

[0018] Exemplary embodiments of the piezoelectric actuator according to the invention will be explained below in conjunction with the drawings.

[0019] Fig. 1 shows a cross section through a piezoelectric actuator with a multilayered structure of layers of piezoelectric ceramic and electrodes according to the prior art,

[0020] Figs. 2 and 3 show piezoelectric layers with inner electrodes of alternating polarities with chamfered corners,

[0021] Fig. 4 shows an exemplary embodiment according to the invention of an electrode design with an obtuse angle in the region of overlapping inner electrodes,

[0022] Figs. 5 and 5a show a second exemplary embodiment according to the invention of an electrode design with rounded edges, and

[0023] Figs. 6 and 6a show another exemplary embodiment according to the invention of an electrode design with inwardly recessed rounded edges.

[0024] Description of the Exemplary Embodiments

[0025] Fig. 1 shows a piezoelectric actuator 1 essentially according to the prior art, which is comprised in an intrinsically known way of piezoelectric layers or piezoelectric sheets 2 of a quartz material with a suitable crystalline structure so that due to the so-called piezoelectric effect, when an external voltage is applied to inner electrodes 3 and 4 via contact surfaces and/or outer electrodes 5 and 6, a mechanical reaction of the piezoelectric actuator 1 occurs.

[0026] Fig. 2 shows a chamfered piezoelectric layer 2, with an inner electrode 3 that is contacted by the outer electrode 5. In the region of the contact of the other inner electrode 4 that can be seen in Fig. 3, on the left side of the piezoelectric actuator 1 according to Fig. 2, an angle a of the chamfered corner with the edge 10 is shown. Since the edges on the piezoelectric actuator 1, as mentioned above in the introduction to the specification, are usually chamfered at an angle of 45°, there is therefore an increased danger of short-circuiting at the corner 10.

[0027] By contrast with the depiction in Fig. 3, the exemplary embodiment according to the invention in Fig. 4 encloses an obtuse angle with the complementary angle of a < 45° so that in this case, field peaks in the piezoelectric actuator 1 are prevented in the regions of inner electrodes 3 and 4 that protrude beyond the piezoelectric layers 2, but on opposite sides.

[0028] The electrode design of the exemplary embodiment in Figs. 5 and 5a is comprised in that the inner electrode 3 is embodied so that it extends tangential to the outer surface of the piezoelectric actuator 1. The inner electrode 3 here is curved around a center point M2 with the radius R2. The outer contour of the piezoelectric actuator 1 can also be curved and, according to Fig. 5a, the inner electrode 3 can also be curved along with the outer contour. For example, this is represented in Fig. 5 by a curvature with a center point M1 and the radius R1.

[0029] In an alternative embodiment according to Fig. 6, the outer contour of the inner electrodes 3 and 4 can also be embodied as straight-edged and the inner electrode 3 according to Fig. 6 that is not contacted here can, according to Fig. 6a, also be recessed inward in a corresponding fashion.